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FINAL

Shock-Absorbing Concrete (SACON) Bullet Traps for Small Arms Ranges Cost and Performance Report

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14. ABSTRACT
The Environmental Security Technology Certification Program funded a technology demonstration of shock-absorbing concrete (SACON) bullet trapping technology. SACON is a low-density, fiber-reinforced, foamed concrete developed by the Structures Laboratory of the Engineering Research & Development Center. It offers significant benefits in comparison to current commercial off-the-shelf bullet trapping technologies. SACON provides a means of effectively capturing and containing lead on small arms ranges without sacrificing training realism. Demonstration objectives focused on identifying and validating the performance, cost, safety, logistics, training realism, and recycling aspects of the SACON material. SACON bullet traps tested in a 25-Meter Range application contained 87 percent of the bullets fired at the trap. Exposure of the bullet debris to the SACON material and weathering resulted in the formation of insoluble lead corrosion products and the generation of nonhazardous waste products. The application of SACON reduced localized soil erosion typically found in the vicinity of target emplacements. Ricochet testing results indicated bullet impacts were within the surface danger zones for the range types chosen for demonstration. A nonrecurring cost of approximately $1600 per land and an annual cost of $3800 per lane were estimated to outfit a 20-lane, 25-Meter Range.

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Lead, Ranges, Small Arms Ranges, Erosion, Shock-Absorbing Concrete, SACON, Bullet Traps

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Another group that was instrumental in the demonstration of the SACON bullet traps was the range managers and personnel at the test installations. Mr. James A. Waterbury at the USMA and Mr. Andy Andrews at Fort Knox provided the test sites, personnel, and data collection support that was critical to the assessment of the demonstration.

Thanks are extended to these and all those who with considerable physical effort toiled to construct and maintain the SACON bullet traps in support of this demonstration.

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I. Executive Summary

Small-arms training is a requirement in all branches of the military. Over 1800 active military outdoor small-arms training ranges are operated in the United States. In a typical year, small-arms training activities consume over 300 million rounds and add between 1 and 2 million pounds of lead to the ranges in the form of bullet debris. As a result, Department of Defense (DOD) small-arms ranges accumulate significant amounts of lead in the soil. Because elevated levels of lead in groundwater and soils can present a health hazard, the migration of heavy metals can result in environmental regulators imposing training restrictions that ultimately will reduce operational readiness. Technology to reduce lead contamination is recognized as a high priority DOD user requirement. The Environmental Security Technology Certification Program (ESTCP) funded a technology demonstration of Shock-Absorbing Concrete (SACON) bullet-trapping technology to address this requirement.

SACON is a low-density, fiber-reinforced, foamed concrete developed by the Structures Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) to be used in the construction of live-fire training facilities such as hand-grenade houses and Military Operations in Urban Terrain (MOUT) villages. SACON was developed to minimize the hazard of ricochets during urban training. The shock-absorbing properties of the concrete necessary to reduce ricochets also function to create a medium for capturing small-arms bullets. In a properly designed SACON bullet trap, the incoming bullet buries itself in the concrete. The low water permeability and high alkalinity of the concrete result in the creation of less soluble lead corrosion products, which reduces the leaching of lead into the surrounding soil. The use of SACON on small-arms ranges provides the DOD with a recyclable bullet-trap material that does not detract from training realism.

Demonstration objectives focused on identifying and validating the performance, cost, safety, logistics, training realism, and recycling aspects of the SACON bullet trap material. Field demonstration of SACON was conducted at the United States Military Academy (USMA) in West Point, New York from April through November 1997 and at Fort Knox, Kentucky from March 1997 through January 1998. SACON recycling was demonstrated at ERDC, Vicksburg in October 1997. Accelerated durability and ricochet testing was conducted at Aberdeen Test Center (ATC) in March 1998.

The lead containment efficiency of SACON was determined in durability testing conducted at ATC. SACON bullet traps tested in a 25-Meter Range application contained 87 percent of the bullets fired at the trap. The majority of the released fraction of bullet debris was deposited immediately in front of the trap forming a debris pile. Lead concentrations in the trap and debris pile exceeded 60,000 mg/kg. In the absence of weathering, the samples exhibited Toxicity Characteristic Leaching Procedure (TCLP) levels that exceeded 5 mg/L, which would result in a hazardous waste classification based on lead toxicity. However all samples taken from SACON bullet traps tested at Ft. Knox and the USMA that were exposed to the effects of weathering resulted in TCLP levels of less than 5 mg/L. Exposure of the bullet debris to the SACON material resulted in the formation of insoluble lead corrosion products. As a result, all SACON

debris removed from these ranges was classified as non-hazardous and disposed of as a solid waste.

Soil erosion resulting from repeated bullet impacts was reduced in front of and behind the target emplacements by burying SACON in these areas. Reducing soil erosion aids in mitigating the physical transport of lead debris from the bullet's impact point on the range. SACON also provides adequate protection of the target coffin when properly maintained. Mitigation of this impact erosion results in less frequent maintenance requirements in these areas. An estimate of a two-thirds reduction in maintenance time for these areas was subjectively made based on visual observations made during the demonstrations.

The cost of installing and using SACON was estimated based on the costs incurred during the conduct of the demonstration and the application of these costs to SACON's potential use on a 20-lane 25-Meter Range. Nonrecurring costs associated with the SACON technology are incurred during the manufacturing, site evaluation, site preparation, and installation processes. Manufacturing costs were derived from a 10-yd^3 batch production rate of 90 lb/ft^3, polypropylene-fiber SACON. This mode of production corresponds to the mixing capacity of a modern transit mixer truck. A nonrecurring cost of approximately $1600 per lane was estimated to outfit a 20-lane 25-Meter Range with SACON bullet traps. The annual recurring costs associated with the use of SACON consists of maintenance, waste management, and replacement SACON block manufacturing. Recurring costs were derived based upon the assumption of an annual throughput of 600,000 M855 bullets on a 20-lane, 25-Meter Range and the durability of the SACON bullet trap designs that were tested. The durability data generated during the demonstration is used to estimate the number of maintenance events that must be conducted annually to maintain the SACON bullet trap. Accelerated durability testing conducted at ATC indicated that a maintenance event will be required after 7,100 rounds are fired into the trap design that was tested. The 600,000 round annual throughput equates to 30,000 rounds fired at a single target on each lane. Based on the measured durability of the SACON bullet trap design tested and its resultant maintenance frequency for the assumed 30,000 round per lane throughput, an annual recurring cost of $3800 per lane was estimated.

Ricochet testing was conducted at ATC to develop data to determine if SACON had any effect on the surface danger zone (SDZ) of the range. ATC measured the ricochet angles, velocities, and distances of two rifle and two pistol rounds after impacting a relatively flat SACON surface. The M855 and M193 rifle rounds were fired on 90 lb/ft^3 SACON blocks while the M882 and M1911 pistol rounds were fired on 70 lb/ft^3 SACON blocks. The Corps of Engineers Engineering Support Center, Huntsville used this data to assess the impact of using SACON bullet traps on the SDZ of the 25-Meter, Automated Record Fire, Automated Field Fire, and the Combat Pistol Qualification Course ranges. The assessment was completed by plotting the termination points of the ricochet projectiles upon the appropriate SDZ as published in AR 385-64. All ricochets resultant from ATC's testing terminated within the respective SDZ.

The procedures employed during bullet trap maintenance were evaluated from a personnel safety perspective. Bullets impacting SACON create debris consisting of SACON chunks, dust, bullet

slugs, and bullet fragments. The dust contains both crushed SACON and lead particles. Personal protective equipment will be required to perform maintenance on SACON barriers to limit lead and dust exposure. Also, the weight of the SACON blocks used in the demonstration exceeded established limits for personnel lifting and handling to perform maintenance. Alternate block designs that utilize mechanical lifting and handling equipment must be used to safely install and maintain SACON bullet traps.

A recycling demonstration conducted at ERDC resulted in the determination that SACON material that has been shot with the M855 5.56mm round cannot be economically recycled using the process employed by ERDC. The process did not meet steel or lead reduction targets established for the demonstration. It should be noted that the applicability of these targets has since been questioned based on the field results of the live fire testing conducted on the recycled SACON blocks. Further testing will be required to establish valid recycling performance criteria. The cost of recovering the aggregate from the used SACON blocks is approximately 100 times the cost of purchasing new aggregate material. Disposal of the used SACON as a solid waste coupled with the purchase of new aggregate material would be approximately 75 percent cheaper than recovering the aggregate material therefore, recycling was not proven to be economically feasible.

SACON, when used in a backstop-type application, compares directly with commercial-off-the-shelf (COTS) bullet traps and the traditional soil berm. Comparisons were based on bullet debris containment, airborne lead emissions, maintenance requirements and frequency, waste handling and disposal requirements, and cost. In general, SACON compared favorably with the COTS bullet traps and soil berm in all areas with the exception of cost. An annual net equivalent value was calculated for each of the technology alternatives. Three categories of range usage and three categories of lead transport risk were defined to aid in the comparison. As exhibited in the table below, on ranges that exhibit a low risk for lead transport the soil berm provides the lowest cost method of capturing rounds. However, as the risk of lead transport from the range increases (lead transport risk should be determined prior to implementing any form of corrective action) the use of bullet traps becomes economically feasible when compared to the prospect of periodically removing the lead from the soil. Due to the maintenance frequency, the SACON bullet traps tested proved to have a higher cost than other commercially available traps

ANEV BY CATEGORY

	Risk		
Usage Rate	Low	Medium	High
High	Conventional Berm	Granular rubber	Granular rubber
Moderate	Conventional Berm	Block rubber	Block rubber
Low	Conventional Berm	Block rubber/SACON	Block rubber/SACON

SACON does provide range managers with a means of effectively capturing and containing lead on small arms ranges. SACON offers significant benefits in comparison to current COTS

technologies. It exhibits an ability to inhibit the leaching of lead corrosion products. Other COTS bullet traps and soil berms do not have this lead stabilization capability. The waste generated from the use of SACON is not classified as a hazardous waste and can be disposed of as a solid waste. SACON is not flammable and can be formed in any shape, making it adaptable to more range applications than standard COTS technologies. However, like all bullet traps, SACON is an expensive means of mitigating the risk of lead transport from ranges and should only be considered as a last resort for keeping ranges environmentally compliant. Other methods of reducing lead transport risk should be investigated prior to installing any bullet trap technology. New methods of stabilizing the lead on the range and mitigating physical lead transport in storm water runoff are being developed and may provide more cost effective means of reducing lead transport risk and bioavailability.

Several shortcomings were identified by the demonstration that necessitate further development of the SACON technology. Further development is required to reduce maintenance costs to levels comparable with the COTS technologies for use on ranges with moderate to high bullet throughput. This can be done through developing less labor intensive maintenance practices and by increasing the durability of the SACON bullet trap designs.

II. Technology Description

SACON is a foamed, fiber-reinforced concrete that contains no coarse aggregate. SACON is classed technically as a foamed mortar with a fiber admixture. Foamed Portland cement-based mortars are produced for industrial applications with densities ranging from 20 lb/ft^3 to densities approaching those of conventional concrete (160 lb/ft^3). SACON has a closed cellular structure that breaks down when a bullet impacts the concrete. In a properly designed target system, the incoming bullet buries itself in the concrete and does not ricochet.

SACON has been used in training activities that utilized the M16 rifle firing the M855 round and the M9 pistol firing the M38 Ball ammunition. When used to stop the M16 rifle round (M855 or M193), the density of the SACON bullet barrier is typically 90 lb/ft^3. For ranges that train with the M9 pistol, SACON barriers are furnished with a density of 70 lb/ft^3. The density that is typically presented for SACON is the density of the foamed sand, cement, and water mixture.

The innovative use of SACON on small-arms ranges provides the DOD with a potentially recyclable material from which to manufacture bullet traps. These traps can be configured to blend into the terrain or to serve as target backstops (Figures II-1 and II-2). When applied in certain range configurations, the use of SACON does not detract from training realism. Lead bullet debris captured by SACON undergoes a corrosion process, resulting in the formation of a relatively insoluble coating of the bullet fragments. Less-soluble lead fragments reduce the leachability of the lead. Reduced solubility and erosion subsequently reduce the potential for lead migration from range areas.

Figure II-1. SACON installed in bullet impact area.

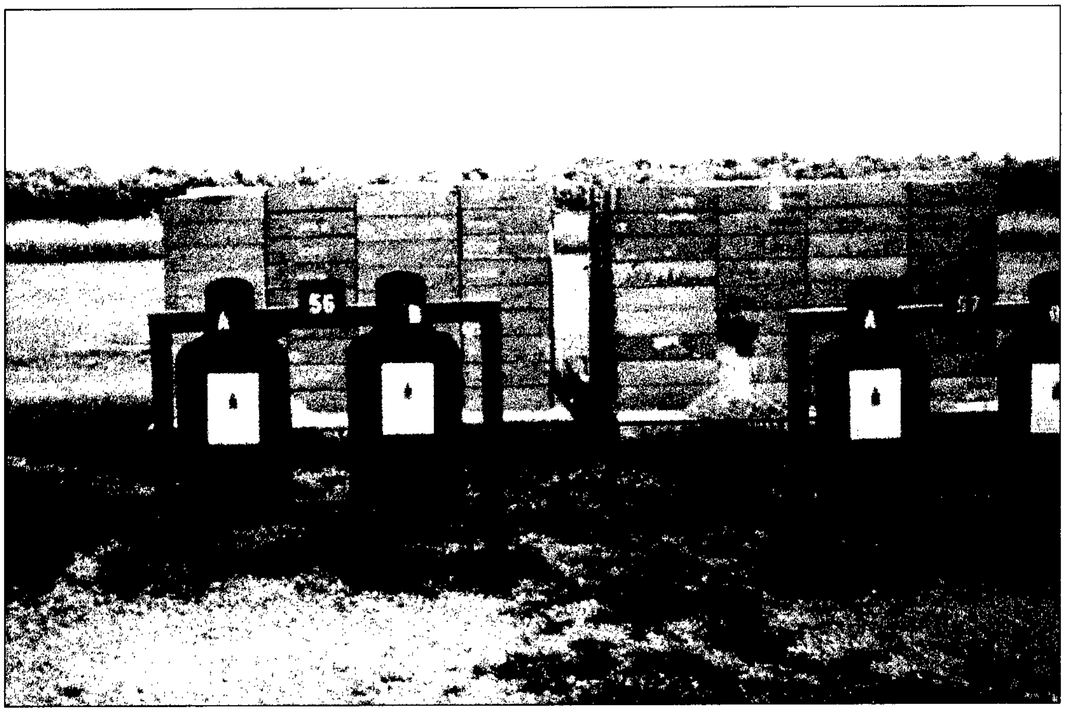

Figure II-2. SACON backstops behind 25-Meter range targets.

The materials required to manufacture SACON are presented in Tables II-1 and II-2. Detailed information on the specifications for fabrication and installation of SACON can be found in *"Using Shock-Absorbing Concrete (SACON) in Bullet Barriers/Traps for Small-Arms Ranges"* (ref. 1).

Table II-1. Materials for SACON with 90 lb/ft^3 density.

Material	kg/m^3	lb/yd^3
Cement (ASTM Types I and II)	577	972
Water	277	466
Aggregate	577	972
Admixture	0.16	0.27
Polypropylene Fiber	8.78	14.8
Foam	329 L/m^3	8.9 ft^3/yd^3

Table II-2. Materials for SACON with 70 lb/ft^3 density.

Material	kg/m^3	lb/yd^3
Cement (ASTM Types I and II)	322	710
Water	145	320
Aggregate	322	710
Admixture	0.11	0.25
Polypropylene Fiber	6.7	14.8
Foam	514 L/m^3	13.9 ft^3/yd^3

Currently the conventional method of stopping bullets on small arms ranges involves the use of soil berms (Figure II-3). The maintenance requirements to operate a range using berms are typically inexpensive and minimal. The maintenance consists primarily of infrequently adding soil to the berm for surface repair. The life expectancy of the berm is the length of time before a soil/bullet removal and cleanup action is required. In the past, berm cleanups were not necessitated by environmental requirements. However, now with the advent of the Military Munitions Rule, contaminant transport from the range may trigger a requirement for periodic range cleanup or implementation of methods to eliminate transport from the range. Future clean-up frequencies will be based upon lead transport risks at individual ranges. The higher the transport risk, the more frequent the need for lead removal. There are five principal parameters that contribute to assessing the overall risk associated with lead migration from a small-arms range. These parameters are ammunition mass fired, corrosion, aerial transport (dust), surface water transport, and groundwater transport. These parameters can be qualitatively assessed using U.S. Army Environmental Center's (USAEC) Range Evaluation Software Tool (REST) (ref. 2).

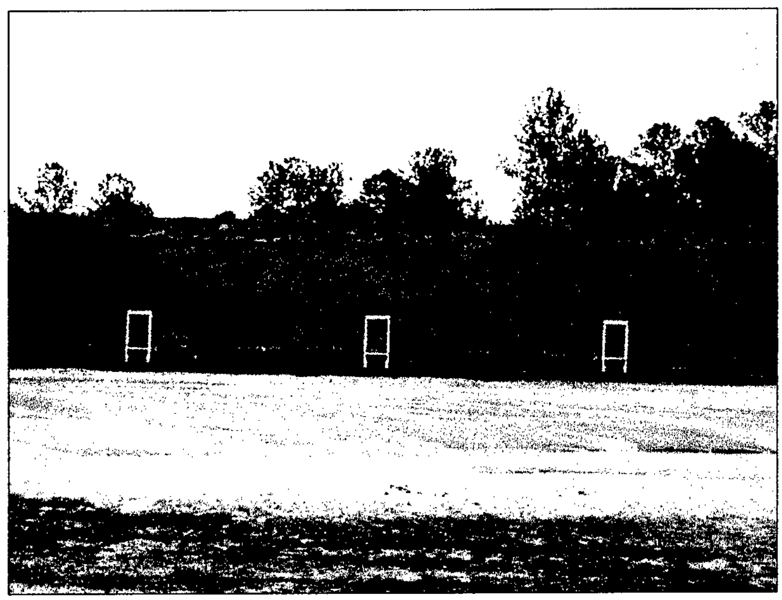

Figure II-3. Small arms range berm.

Bullet traps provide a means of controlling lead mass transport from small arms ranges. Many commercially available bullet trapping options are available for range use (Figures II-4, II-5, and II-6). Descriptions of these traps and others can be found in USAEC's *Bullet Trap Feasibility Assessment* (ref. 3) and *Demonstration of Commercial Bullet Trap* (ref. 4) reports. SACON, when used in a backstop-type application, compares directly with COTS bullet traps and the traditional soil berm. Comparisons were based on bullet debris containment, airborne lead emissions, maintenance requirements and frequency, waste handling and disposal requirements, and cost. In general, SACON compared favorably with the COTS bullet traps and soil berm in all areas with the exception of cost. An annual net equivalent value was calculated for each of the technology alternatives. Three categories of range usage and three categories of lead transport risk were defined to aid in the comparison. As expected, on ranges that exhibit a low

risk for lead transport the soil berm provides the lowest cost method of capturing rounds. However, as the risk of lead transport from the range increases (lead transport risk should be determined prior to implementing any form of corrective action) the use of bullet traps becomes economically feasible when compared to the prospect of periodically removing the lead from the soil. Due to the maintenance frequency, the SACON bullet traps tested proved to have a higher cost than other commercially available traps

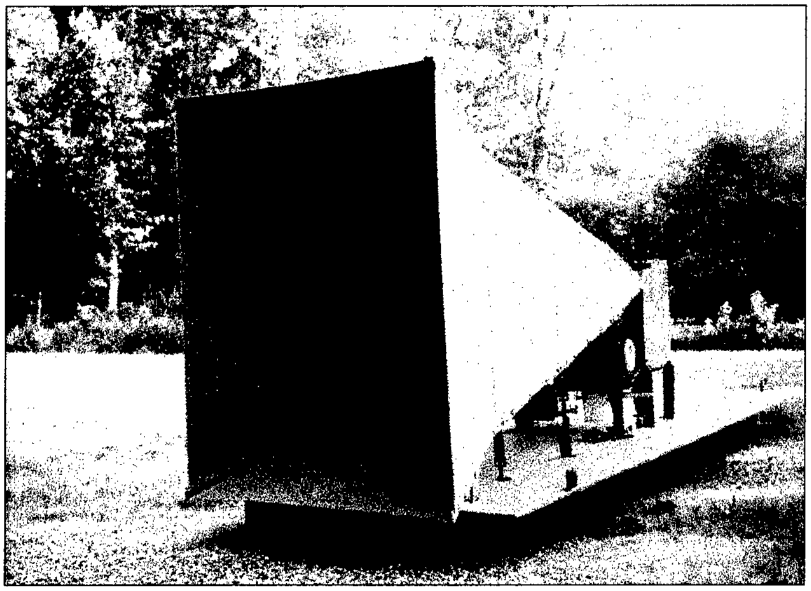

Figure II-4. Deceleration trap.

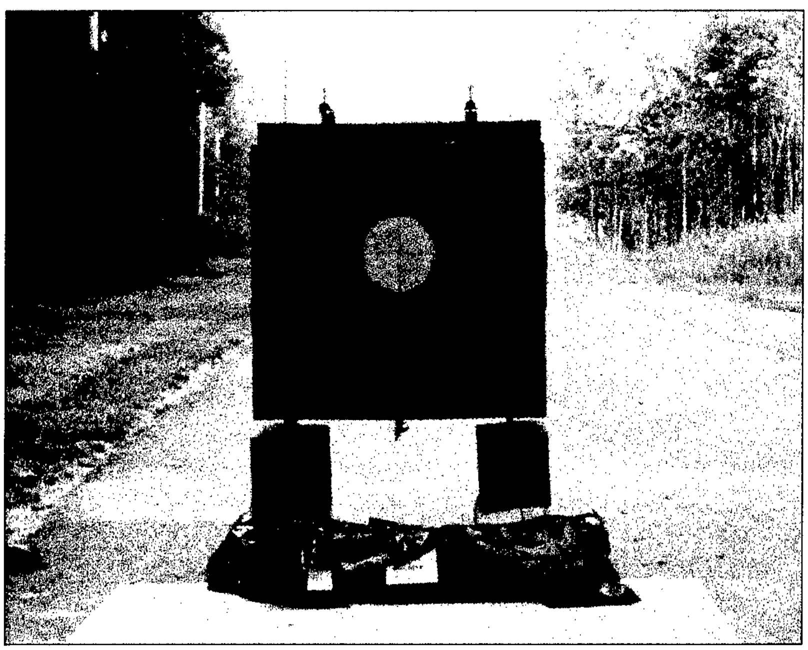

Figure II-5. Rubber block trap.


Figure II-6. Granular rubber trap.

Advantages. SACON has a number of characteristics that make it valuable as a bullet-trapping medium when compared to traditional berm technology. The low permeability of SACON reduces the amount of lead (from bullet debris) that is exposed to weathering on the range. The high alkalinity of SACON can reduce the rate of lead corrosion and decrease the solubility of the lead corrosion products, thus lowering the amount of lead available for migration. SACON can also be used to stabilize areas typically rutted by bullet impacts, such as around target coffins or within berm cavities.

While debris removed from soil berm cavities has been found to have leachable levels of lead greater than 5 ppm, SACON debris when analyzed for leachable lead content was consistently non-hazardous (less than 5-ppm TCLP lead). Debris samples taken from friction traps constructed of media other than SACON have consistently failed the TCLP criterion for a characteristic hazardous waste based on lead concentration. The hazardous classification results in more expensive handling and disposal requirements for the range debris generated from the use of traps using rubber or soil as the friction media. The reduced mobility of lead created by SACON makes landfill disposal a viable option.

SACON can be crushed to reclaim bullet debris and to produce an aggregate for use in the manufacture of additional SACON although the recycling will be governed by the type of ammunition used and economics. SACON can be manufactured and colored into shapes typical to ranges. The installation of SACON does not require extensive site preparations, with SACON walls requiring only a level, solid foundation.

Another advantage SACON has over other friction trap materials such as rubber blocks, granular rubber, or wood is that SACON does not burn. During hot, dry weather, the range fires become a potential problem. Range fires can be caused by a number of mechanisms including tracer

rounds, muzzle flash, and lightning. Rubber bullet traps on the range are susceptible to consumption by the range fire. Burning rubber could complicate fighting range fires by creating a hot, smoky fire that produces complex hydrocarbons generally containing carcinogens. Rubber fires produce a thick, black smoke visible for miles that can generate nuisance complaints from neighbors and inquiries from the regulatory community.

SACON does not have to be treated with any preservative, will not rot, and is not subject to attack by insects. SACON will not photo-degrade and contains no potentially toxic organic compounds that can appear in water leaching from the material. SACON can be locally manufactured and can be camouflaged with range terrain.

SACON offers advantages over steel deceleration type traps in that no back-splatter and less lead dust are created.

Weaknesses. The manufacturing of SACON requires careful quality control to ensure that the correct densities are produced and that only the proper size aggregate is used. Improper manufacturing has the potential to create safety problems. SACON with densities or aggregates greater than required may create a ricochet hazard.

At the present time, the recycling of SACON bullet-trap media is not economically advantageous. The configuration or shape of the SACON products has a significant effect on its durability. Shapes with curved surfaces were observed to deteriorate faster during use than shapes with flat surfaces. SACON barrier design improvements are needed to reduce handling requirements, improve durability, and reduce costs.

III. Demonstration Design

A. Performance Objectives

The demonstration was designed to identify and verify the economic, operational, and environmental performance data that will be used to validate and promote the use of SACON as a bullet trapping medium to potential users. Six major factors were evaluated during the various field demonstrations conducted under this program: performance, life-cycle costs, safety, logistics, training realism, and the ability to recycle the spent materials. Table III-1 outlines the objectives that were addressed during the demonstration. The performance criteria established to support the successful use of SACON on military small arms ranges and for recycling are presented in Table III-2.

TABLE III-1. OBJECTIVES

Objective 1.0	**Assess the performance of SACON bullet traps on small-arms firing ranges.**
1.1	Assess the number of rounds not retained by the SACON bullet traps.
1.2	Determine if debris is RCRA hazardous waste based on toxicity characteristics.
1.3	Assess the effect of SACON bullet traps on impact erosion.
1.4	Assess the effect of SACON on target protection.
Objective 2.0	**Determine the life-cycle costs associated with using SACON bullet traps.**
2.1	Determine the nonrecurring costs associated with SACON bullet traps.
2.2	Determine the recurring costs associated with SACON bullet traps.
Objective 3.0	**Assess selected safety issues related to using SACON bullet traps.**
3.1	Determine if SACON bullet traps produce ricochets.
3.2	Assess personnel safety during SACON barrier installation and maintenance.
Objective 4.0	**Assess selected logistical issues associated with SACON.**
4.1	Assess the maintainability of the SACON bullet traps.
4.2	Assess the durability of the SACON bullet traps.
Objective 5.0	**Assess the impact of SACON bullet traps on training realism.**
5.1	Assess the distraction to the shooter caused by the SACON bullet traps.
5.2	Assess the down-range visibility impact caused by SACON.
5.3	Assess the ability of the SACON to conceal target location.
Objective 6.0	**Assess the performance, costs, and safety aspects of recycling SACON.**
6.1	Determine the ability to remove steel penetrators and/or steel fibers.
6.2	Determine the ability to reduce toxicity characteristics.
6.3	Determine the ability to contain and control lead.
6.4	Determine if the waste material generated is a hazardous waste.
6.5	Determine the ability to generate a usable fine aggregate.
6.6	Determine the ability to produce SACON conforming to specifications.
6.7	Determine the nonrecurring (capital) cost associated with recycling.
6.8	Determine the recurring cost associated with SACON recycling.
6.9	Assess personnel safety during SACON recycling operations.
6.10	Determine the adequacy of personnel protective equipment.

TABLE III-2. TEST CRITERIA

Objective	Description	Criteria
	1.0 Performance	
1.1	Bullet containment efficiency	98%
1.2	Characterization of waste products	<5 ppm leachable lead
1.3	Reduction of impact erosion	None
1.4	Adequacy of target protection	None
	2.0 Costs	
2.1	Nonrecurring costs	None
2.2	Recurring costs	None
	3.0 Safety	
3.1	Ricochet hazard	AR 385-64
3.2	During installation and maintenance	OSHA 29 CFR 1910
	4.0 Logistics	
4.1	Maintainability	None
4.2	Durability	None
	5.0 Training Realism	
5.1	Distraction	None
5.2	Visibility impact	None
5.3	Ability to conceal	None
	6.0 Recycling	
6.1	Steel removal efficiency	>95% removal
6.2	Reduction of toxicity characteristics	<5 ppm leachable lead
6.3	Containment and control of lead	<200 ppb per square foot accumulation
6.4	Characterization of waste products	<5 ppm leachable
6.5	Production of usable fine aggregate	Meets specification
6.6	Physical characteristics	<5% deviation
6.7	Nonrecurring costs	None
6.8	Recurring costs	None
6.9	Personnel safety during recycling	OSHA 29 CFR 1910
6.10	Personal protective equipment	OSHA 29 CFR 1910

ppm = Parts per million.
ppb = Parts per billion.

B. Physical Setup and Operation

Field demonstration activities were conducted at USMA from April through November 1997 and at Fort Knox from March 1997 through January 1998. Various applications of SACON was tested on 25-Meter ranges, Automated Record Fire (ARF) ranges, an Automated Field Fire (AFF) range, and a Combat Pistol Qualification Course (CPQC) at these installations. The

recycling operation and testing was conducted in October 1997 at the ERDC's Structures Laboratory. Accelerated durability and ricochet testing was conducted at ATC in March 1998. Figure III-1 matches demonstration objectives that were assessed to the locations where the major data used to assess the specific objectives were generated.

RANGES	1-1 Fragment Containment	1-2 Toxicity Characteristics	1-3 Impact Erosion	1-4 Target Protection	2-1 Capital Costs	2-2 Recurring Costs	3-1 Riccochet Characteristics	3-2 Personnel Safety	4-1 Maintainability	4-2 Durability	5-1 Firer Distraction	5-2 Downrange Visibility	5-3 Target Concealment	6-1 Steel Removal	6-2 Toxicity Characteristics	6-3 Lead Containment	6-4 Waste Characterization	6-5 Production of Aggregate	6-6 Physical Characteristics	6-7 Non recurring costs	6-8 Recurring costs	6-9 Personnel Safety	6-10 Protective Equipment
Fort Knox																							
25-Meter Range		●					●	●	●	●	●												
Automated Record Fire Range (ARF)		●	●	●					●			●	●										
Automated Field Fire Range (AFF)		●	●	●					●			●											
Combat Pistol Qual. Course (CPQC)		●	●	●					●			●											
USMA																							
25-Meter Range	●	●			●	●	●	●	●	●	●												
Automated Record Fire Range (ARF)			●	●					●			●	●										
ATC	●	●				●	●	●	●	●													
WES														●	●	●	●	●	●	●	●	●	●

Figure III-1. Objectives versus primary data collection locations.

C. Measurement of Performance

A demonstration plan (ref. 5), originally developed by the Defense Evaluation Support Activity (DESA) and modified by ATC, was used to guide the data collection and technology assessment. A three-tier approach to gather data was used to support assessment of the SACON. The tiered approach to data acquisition is illustrated in Figure III-2. The data assessment methods specific to each demonstration objective identified in Table III-1 are fully described in the final report (ref. 6).

The first tier consisted of active participation by DESA, ATC, or ERDC during selected key demonstration events. This participation included monitoring installation of the SACON barriers, collection of samples, conducting periodic inspections, monitoring of overall data collection, and monitoring of removal operations. ERDC and ATC monitored and collected samples during SACON recycling operations. ATC gathered additional durability, ricochet, and TCLP data to fill data gaps identified in a midpoint program review. ATC also supplemented the evaluation survey and manual data collection forms with photographs and video recordings of the demonstration. These recordings were used to characterize impact erosion and target protection and to supplement the maintainability, durability, and safety assessment of the SACON barriers.

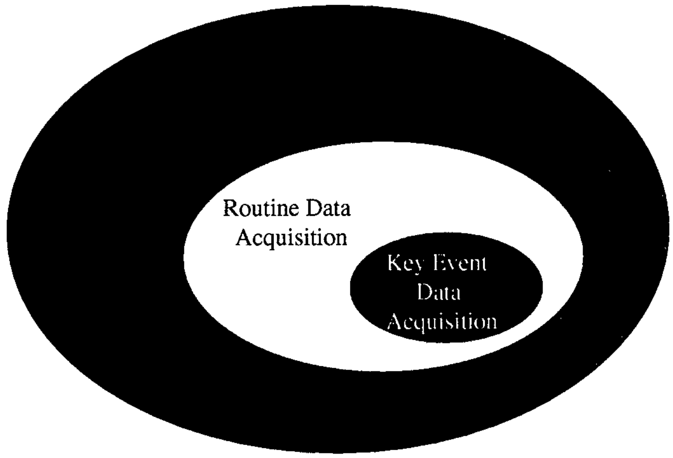

Figure III-2. Data acquisition approach.

Second-tier data was collected by installation range personnel. Second-tier data included environmental and technology performance sampling of the debris in front of the two SACON barriers at USMA, a monthly assessment of SACON block durability and maintainability by range operators, and a daily recording of rounds fired on SACON-equipped firing lanes.

Third-tier data was obtained through literature reviews and other research on cost, safety, maintainability, and training realism information not obtainable through observation. The majority of this data was obtained from USAEC and ERDC publications or through interviews with installation range managers.

D. Demonstration Site/Facility Background and Characteristics

The field test sites were selected to provide both operational data and detailed performance data. User input was gained through the application and use of SACON on training ranges located at USMA West Point and Fort Knox. These two sites were selected jointly by USAEC and the U.S. Army Training Support Center (ATSC). USMA agreed to the placement of SACON on both 25-Meter and ARF Ranges and to the collection of debris samples. Fort Knox allowed SACON to be placed on 25-Meter, AFF, ARF, and CPQC Ranges. The range site selections were made based upon willingness to provide data collection support for the demonstration, existence of applicable small-arms range types, and training schedules.

Routine maintenance and the environmental assessment of ranges are not specifically addressed in any single Federal regulation. However, portions of different Federal regulations could be applicable in certain situations and should be considered. Federal laws such as the Clean Water Act (CWA); Safe Drinking Water Act; Resource Conservation and Recovery Act (RCRA); and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) can be applied to active small arms ranges (ref. 7). For example, in April 1997, the US

Environmental Protection Agency (USEPA) Region I relied on the Safe Drinking Water Act to impact training operations at the Massachusetts Military Reservation. This was based on allegations that ongoing training activities caused an imminent and substantial threat of contamination to the sole source aquifer under the impact area. None of the demonstration sites are currently experiencing compliance issues with any Federal regulations as a result of range use nor are there any known potential environmental problems at these sites. An assessment of the fate and effects of the metals placed on these ranges was not conducted under this program. All data collection was restricted to the specific applications of SACON on the ranges and only the performance of the SACON was assessed.

The National Environmental Policy Act (NEPA) and AR 200-2 requires environmental documentation for all federal actions (e.g. military training, new technology/equipment testing, construction projects, and real property transactions). Documentation of the SACON testing at ATC consisted of completing a Record of Environmental Consideration (REC) prior to testing. No potential environmental impacts were identified and testing activities met the AR 200-2, A-12 requirements for categorical exclusion. The federal and state regulatory community was not involved prior to or during the demonstration.

IV. Performance Assessment

Performance. SACON bullet traps, as designed and tested in a 25-Meter Range application, contained 87 percent of the bullets fired within the trap. The majority of the bullet debris released was localized immediately in front of the trap within a debris pile (Figure IV-1). Testing of the trap and debris pile resulted in total lead levels exceeding 60,000 mg/L. In the absence of time and weathering, the samples exhibited characteristics that would result in a hazardous waste classification based on lead toxicity. This occurred in samples collected during accelerated testing at ATC. During normal range use sufficient time and exposure results in the formation of insoluble corrosion products which greatly reduces the leachable lead fraction. All samples taken from SACON barriers at Ft. Knox and the USMA that were exposed to weathering conditions resulted in a leachable lead fraction (USEPA Method 1311) of less than 5 mg/L. This indicates that when used SACON becomes a waste (i.e. requires removal from the range) it will not be classified as a hazardous waste based on lead toxicity.

Buried SACON in front of and behind the target emplacements appeared to reduce erosion created by repeated bullet impacts (Figures IV-2 and IV-3). This was qualitatively measured by surveying the range managers at USMA and Ft. Knox. SACON also provided adequate protection of the target coffin when maintained appropriately.

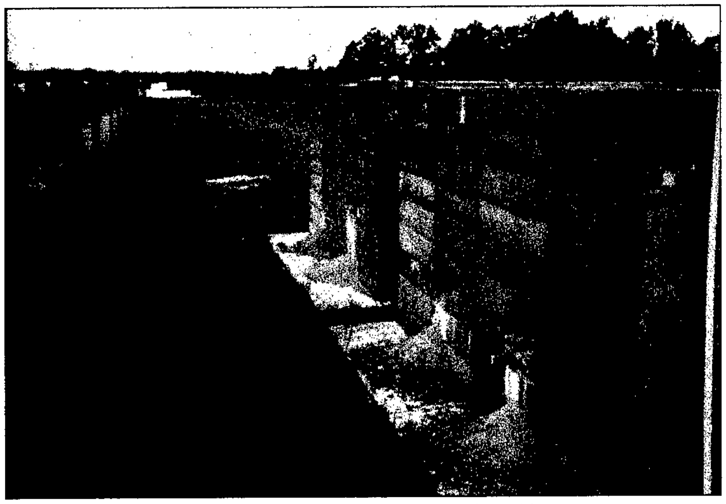

Figure IV-1. Bullet debris piles.

Figure IV-2. Typical ARF range bullet impact erosion.

Figure IV-3. Impact erosion 16 months after SACON installation.

Safety. The Corps of Engineers Engineering Support Center, Huntsville assessed the impact of using SACON as a bullet trap upon the SDZ for the 25-Meter, ARF, AFF, and the CPQC ranges. The assessment was completed by plotting the termination points of the ricochet projectiles upon

the appropriate SDZ (Figure IV-3) for small arms as published in AR 385-64. The ATC measured the ricochet angles, velocities, and distances of two rifle and two pistol rounds after impacting a relatively flat SACON surface.. The M855 and M193 5.56mm rifle rounds were fired against 90 lb/ft3 SACON while the M882 and M1911 pistol rounds were fired against the 70 lb/ft3 SACON. All ricochets resultant from ATC's testing terminated within the respective SDZ.

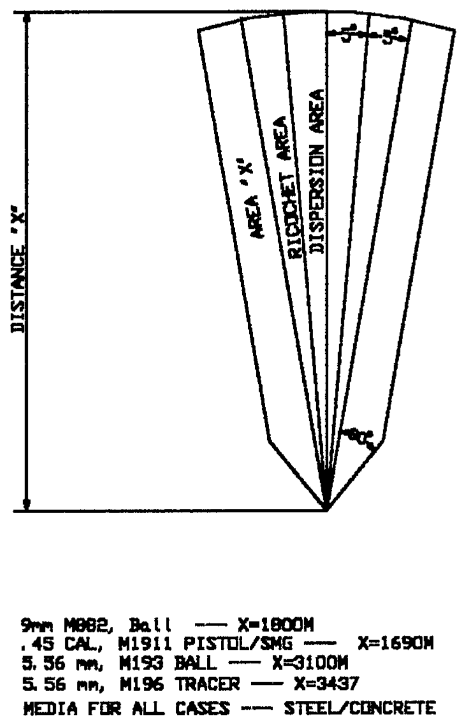

Figure IV-4. Generic SDZ diagram.

The procedures employed during barrier refurbishment were evaluated from a personnel safety perspective. Bullets impacting SACON creates debris consisting of SACON chunks, dust, bullet slugs, and bullet fragments. The dust contains both crushed SACON and lead particles. Personal protective equipment will be required to perform maintenance on SACON barriers. As a result of the mass of many of the SACON blocks, lifting and stacking requirements to perform maintenance exceed human engineering criteria. As a result, the use of man portable SACON blocks will not be feasible in many situations. Appropriate lifting and handling equipment will be required to install and maintain SACON bullet traps.

Logistics. User comments were solicited to evaluate the maintainability of the SACON bullet traps. The weights of the individual blocks were determined to be too heavy for personnel lifting (Figure IV-5). Rearranging worn blocks was a labor-intensive operation and was necessitated by the failure of only two blocks within a large stack. Lead dust creates a potential for lead inhalation exposure and thus must be mitigated through personal protective equipment. The wire used in the manufacture of the steel-reinforced SACON produced debris that caused punctures

through leather gloves. In general, more time was spent maintaining SACON backstops than in maintaining the timbers and wooden logs currently used as backstops on some ranges. The exception was in using SACON in the berm in front of target positions on the ARF, AFF, and CPQC ranges. A two-thirds reduction in maintenance time was estimated by some range personnel for this SACON application.


Figure IV-5. Four-man lift - 200-pound SACON block.

The durability data generated can be used to estimate the number of block rotations that will be necessary each year. Accelerated durability testing indicated that one firing cavity (90 lb/ft^3 SACON) can receive 7,100 M855 rounds before a block rotation. Using the annual range usage rate extrapolated from the field demonstrations and utilizing the wear rates generated by ATC's accelerated durability testing (Figure IV-6), block rotations on the 25-Meter range backstops are estimated to be required every two years at USMA and every three years at Ft. Knox.

Training Realism. Each soldier who fired a weapon on an SACON-outfitted range was asked to complete a training realism survey. The survey results indicate the following:

- The size and location of the SACON barriers were not a significant distraction to the shooter.
- The location of SACON did not impact visibility of down-range targets.
- The size and location of the SACON around the target did not significantly aid target identification.
- SACON's color and texture did not impact visibility of down-range targets.

Shock Absorbing Concrete Demonstration
Durability Subtest - March 1998
Density 90lbs/cu.ft

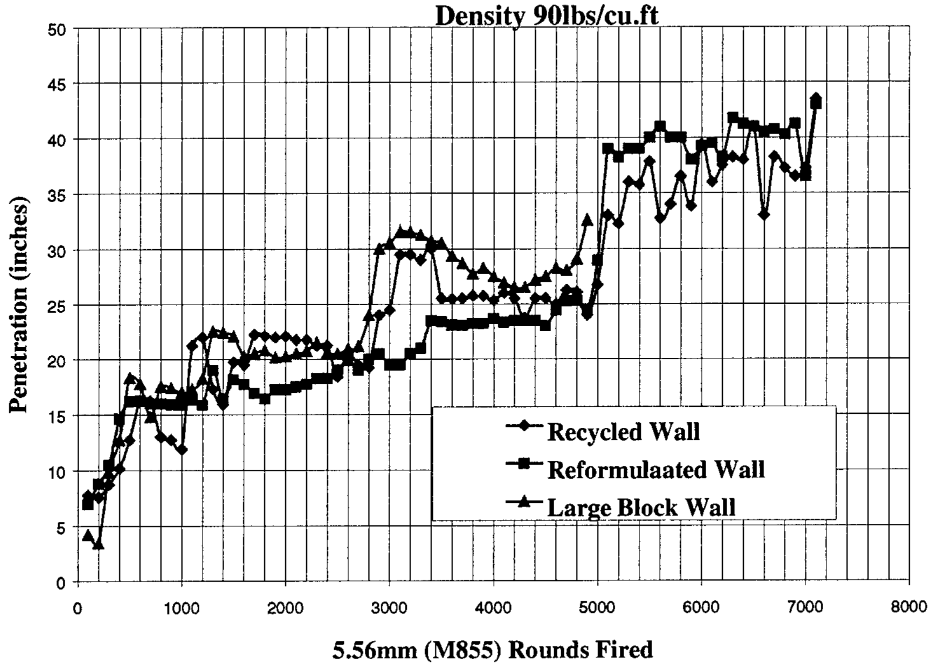

Figure IV-6. Depth-of-penetration versus round count comparison.

Recycling. A mixture of worn and new SACON blocks was recycled at ERDC to assess SACON recycling capabilities. The process demonstrated did not meet the established steel removal criteria. Results on lead toxicity reduction were inconclusive because TCLP results were less than 5 mg/L before and after the separation process. Lead concentration results indicate that a significant amount of fine lead particles were present and passed through the sieve set.

Fugitive dust levels were taken to determine the ability of the recycling process to contain and control lead during recycling. Based on the airborne lead levels measured during the recycling operations, it appears that over time unconfined recycling operations would eventually contaminate the recycling site.

Waste products remaining after recycling were analyzed for lead toxicity. All TCLP results were less than the established limits and no hazardous wastes were generated.

The recycling process failed to produce an aggregate meeting ASTM C144 or ASTM C33. Also, the compressive strength of the SACON produced using the recycled aggregate deviated beyond the established criteria.

The cost of recovering the aggregate from the used SACON blocks is approximately 100 times the cost of purchasing new aggregate material. Disposal of the used SACON as a solid waste

coupled with the purchase of new aggregate material would be approximately 75 percent cheaper than recovering the aggregate material.

Based on these results and the established performance criteria, it was determined that the SACON blocks could not be effectively or economically recycled as a field operation. Recycling by a commercial recycling firm is also not economically feasible due to the relatively low lead content of the SACON debris.

V. Cost Assessment

The cost of using SACON to mitigate lead impacts on small arms ranges was derived by estimating the nonrecurring (installation) and recurring (operational) costs for a 200-foot wide, outdoor, 20-lane, 25-meter range. These costs were extrapolated from the demonstration data using the guidance provided by the Environmental Cost Analysis Methodology (ECAM) Handbook (ref. 8). In order to determine a range of applicability for the SACON technology from an economics perspective, an operational scenario with varied throughputs was selected for the purpose of technology comparison. The operational scenario consisted of standard outdoor 25-meter range training operations with high (30,000 rounds per firing lane), moderate (15,000 rounds per firing lane), or low (7,500 rounds per firing lane) annual throughput. Heavy metals transport risk was also factored into the economics comparison. An assumption was made that with the implementation of the DoD Range Rule, the time period between range soil cleanup efforts is proportional to the time period resulting in off-range migration of metals. The cleanup frequency required to comply with the DoD Range Rule will directly impact range operational costs. To factor cleanup frequency into the cost comparisons, low-, moderate-, and high-risk scenarios were assumed. Basically, high risk equated to a required cleanup effort in 5-year increments, moderate in 15-year increments, and low in 50-year increments.

Nonrecurring costs associated with the SACON technology are incurred during the manufacturing, site evaluation, site preparation, and installation processes. Cost factors were derived for each of these processes based upon a scenario of installing barriers on 20 lanes of a 25-Meter Range. Manufacturing costs were derived from a 10-yd^3 batch production rate of 90 lb/ft^3, polypropylene-fiber SACON. This batch mode of production corresponds to the mixing capacity of a modern transit mixer truck. The batch mode of SACON manufacturing results in a production cost of approximately $297 per cubic yard. The manufacturing, site evaluation, preparation, and installation result in a cost of approximately $1600 per lane to outfit a 20-lane 25-Meter Range with SACON bullet traps.

Recurring costs associated with the use of SACON technology can be broken into three categories: maintenance, waste management, and SACON manufacturing. Cost factors were derived for these recurring cost categories based upon use of SACON on a 20-lane, 25-Meter Range with an annual throughput of 600,000 M855 bullets. This equates to 30,000 rounds fired at a single target area on each lane. An approximate recurring cost of $3800 was determined based upon this scenario. The recurring and nonrecurring costs for this range and use scenario are detailed in Table V-1.

TABLE V-1. SACON COSTS - 25-METER RANGE, 20 LANES, EACH RECEIVING 30,000 ROUNDS PER YEAR

Direct Process Cost				Annual Environmental Activity Cost		Other Costs	
Start-Up		Annual Operation and Maintenance					
Activity	$	Activity	$	Activity	$	Activity	$
Equipment purchase (60 yd^3 SACON)	17,820	Labor to maintain	39,150	Solid waste management	360	Final disposal	17,664
Equipment integration/site evaluation	3,440	Miscellaneous overhead (ordering supplies, etc.)	1,000			Productivity/cycle time	Unchanged
Site preparation: 5-day skid loader rental; gravel; 3 laborers, 40 hr at $30/hr	4,871	Utilities	NA	Environmental management plan development and maintenance, Environmental Protection Specialist, 24 hr at $45/hr	1,080	Worker injury claims and health costs	NI
Installation: 2.5 hours x 4 laborers x $30/hr x 20 lanes	6,000	Operator refresher training (4 persons x 2 hr x $30/hr	240	Reporting requirements	NI		
Training of operators: 4 operators, 10 hr at $30/hr	1,200	Solid waste disposal fees and materials (145,920 lb/yr at $0.08 lb)	16,261	Test/analyze waste streams, 4 TCLPs/yr	1,500		
		Consumables and supplies (60 yd^3 SACON)	17,820	Medical exams (including loss of productive labor)	NI		
		Equipment maintenance	NI	Waste transportation (on and off site)	[a]-		
				OSHA/EHS training	960		

[a]Included in hazardous waste disposal fee.

NA = Not applicable.
NI = No increase over current costs.

To develop comparisons among the existing soil berm technology, available COTS technologies, and the SACON technology, both direct and indirect process cost data were developed for each technology. A direct cost is an accounting term for costs that are clearly and exclusively associated with a product or service. Correspondingly, indirect process costs are those not exclusively associated with the process or service. The origin of the data used to develop both direct and indirect process cost data was primarily from this demonstration, a related COTS bullet-trap technology demonstration conducted by ATC, engineering judgments, and interviews with Range Managers.

A direct comparison of SACON with the existing technology alternatives was made by determining the annual net equivalent value (ANEV) cost of implementing and using each of the technologies. The ANEV calculation transforms present and future costs to annual costs for direct comparison purposes. Assumptions used to calculate the ANEV were an interest rate of 3.65 percent and a 15-year life. Cost data for competing technologies have been summarized in Table V-2 for use in the ANEV analysis.

TABLE V-2. HIGH-USE RANGE - BULLET-TRAP TECHNOLOGY COST COMPARISON SUMMARY

Technology	Start-Up, $	Annual Operation and Maintenance, $	Annual Environmental Activity Costs, $	Disposal, $
SACON	33,331	74,471	3,900	17,664
Conventional berm	58,920	2,600	480	1,176,000
Deceleration (COTS)	316,270	No estimate	No estimate	340,500
Block rubber	132,895	30,664	4,440	30,123
Granular rubber	229,035	[a]18,224	2,505	50,050

[a]Excluding metals recovery. Metals recovery factored in as a future cost every n years.

The high-use range ANEVs derived are presented in Table V-3.

TABLE V-3. HIGH-USE RANGE - ANNUAL NET EQUIVALENT VALUE COMPARISON

Technology	ANEV Cost		
	Low Risk, $	Medium Risk, $	High Risk, $
Conventional	[a]14,237	68,525	406,266
SACON	82,201	82,201	82,201
Deceleration	No estimate	No estimate	No estimate
Block rubber	48,309	48,309	48,309
Granular rubber	47,707	47,707	47,707

[a]Based upon a 50-year berm life.

Moderate- and low-use ranges had lower ANEV costs for the bullet trapping technologies because less usage results in less maintenance and reduced consumable supply usage. The technologies with the lowest ANEV costs based on usage rate and lead transport risk are summarized in Table V-4. For the low usage, medium- and high-risk categories, the block rubber and SACON had essentially the same ANEV. Based upon the economic data presented, the range of applicability for the SACON technology would be on ranges of medium to high risk with low- to moderate-usage rates.

TABLE V-4. ANEV BY CATEGORY

	Risk		
Usage Rate	Low	Medium	High
High	Conventional Berm	Granular rubber	Granular rubber
Moderate	Conventional Berm	Block rubber	Block rubber
Low	Conventional Berm	Block rubber/SACON	Block rubber/SACON

VI. Implementation Issues

A. Cost Observations

Several factors influence the cost of using SACON bullet traps. Cost can be influenced by the scale of manufacture, configuration (shape) of the SACON products, installation on the range, range throughput and bullet-trap durability, maintenance frequency, maintenance techniques, and waste recycling or disposal availability. These factors and their effects are summarized in Table VI-1.

Cost reduction can be achieved for use of SACON on ranges in many ways. This can be done through developing less labor intensive maintenance practices and by increasing the durability of the SACON bullet trap designs. Development of larger, non-man portable blocks would increase reliance on mechanized material handling equipment but significant labor hours could be saved. In concert with the use of larger blocks, a method to patch the blocks in place would result in lower costs. This would reduce the volume of material requiring disposal to only the debris from the bullet cavities. Also, incorporation of the debris material as a feedstock to the patch mix would further reduce disposal volumes. Further testing should be conducted to enhance the durability of free-standing SACON objects placed on the ARF, AFF, and CPQC Ranges.

TABLE VI-1. FACTORS INFLUENCING COST

Cost Categories	Factors Influencing Categories	Effects Produced By Factors
Fabrication	Scale of Manufacture (Quality Control)	Premium prices may be charged for fabrication of small volumes of SACON.
	SACON Configuration	Complicated molds increase cost and fabrication time.
Installation	Range Application	Determines the type of site preparation and the accessibility of material handling equipment.
	Site Preparation	Costs vary with site preparation requirements.
	Material Handling	Ability to use material-handling equipment reduces manpower requirements and installation timeframe.
Maintenance	Range Throughput	A high number of personnel using the range will result in more frequent maintenance.
	Durability	Durability varies with range application and throughput affecting maintenance frequency and range availability.
	Debris Removal	Requires waste handling training and appropriate personnel protective equipment (PPE).
	Waste Classification	Sampling and analysis are required to determine the waste handling and disposal requirements. Waste classification may be dependent upon range throughput. Record keeping required.
	Waste Handling	Range residue produced requiring proper handling, storage, disposal, and record keeping. Volume of waste is dependent upon range throughput.
	Refurbishment	Durability, throughput, and range application dependent. Generation of replacement SACON necessary.
Recycling/ Disposal	Disposal/Recycling	Waste material characteristics and volume generated are throughput and application dependent. Aggregate value and cost to generate should be compared to disposal fees.

B. Performance Observations

In terms of performance on the ranges, SACON generally performed as it was expected. The demonstrations showed that SACON performance can be influenced by manufacturing quality control, configuration of the SACON bullet traps, method of installation, and location of the SACON on the range. The durability and labor requirements for maintenance prevented the achievement of a low-cost bullet trap for a wide variety of range applications. Further

developmental work is required to enhance durability and reduce the maintenance burden. The recycling performance goals were not achieved. The validity of the established benchmarks for the recycling operations were questionable. Because of the SACON chemistry, direct incorporation of SACON debris may be possible with little or no processing. Validation testing to ensure SACON safety criteria can be maintained with direct incorporation of the debris is required.

C. Other Significant Observations

SACON does provide range managers with a means of effectively capturing and containing lead on small arms ranges, specifically in 25-Meter range backstop applications and buried blocks to mitigate impact erosion around targets. However, like all bullet traps, SACON is an expensive means of mitigating the risk of lead transport from ranges and should only be considered as a last resort for keeping ranges environmentally compliant. Other methods of reducing lead transport risk should be investigated prior to installing any bullet trap technology. New methods of stabilizing the lead on the range and mitigating physical lead transport in storm water runoff are being developed and may provide more cost effective means of reducing lead transport risk and bioavailability.

At its current level of development, SACON is ready for application to small arms ranges where the risk for lead migration from the range cannot be mitigated by existing erosion control methods. Implementation guidance is available in the form of a SACON Construction Manual. The manual provides instructions for manufacturing and installing SACON for various range applications. The manual can be used to develop procurement specifications for specific range applications. It is available at the following world wide web address:http://aec-www.apgea.army.mil:8080. Technical assistance with the application and manufacture of SACON is also available via USAEC's hotline (1-800-USA-3845) or email: t2hotline@aec.apgea.army.mil and from ERDC's structures laboratory by contacting Dr. Philip Malone, (601) 634-3960.

D. Lessons Learned

SACON technology has been in existence for years. However, acceptance of this, or any technology designed to mitigate lead migration from small arms ranges, will be limited until the impact from environmental regulatory directives is felt on range operations and troop readiness. Technology acceptance on small arms ranges may also be impacted by inconsistencies in the definition of user needs. The requirements for small arms training and the methods of conducting training is well understood, however, the requirements for range upgrades, whether they are environmentally or operationally driven, is not clearly defined. Prior to implementation of any range upgrades, range operational requirements should be clearly defined to ensure that the range upgrades are completed in a manner that meets user needs. Investigation into the modes of lead transport and the extent of the lead mobility is required to clearly define environmental performance targets for range upgrades. The formalization of requirements would enable the range designer to better configure SACON, or other lead mitigation technologies, to

meet operational requirements. Defining operational requirements with specific performance requirements for user acceptance would allow environmental dollars to be leveraged to maximize environmental compliance and to simultaneously enhance training capabilities.

References

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8. Environmental Cost Analysis Methodology (ECAM) Handbook, National Defense Center for Environmental Excellence, 7 January 1998.

Appendix A. Points of Contact

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Appendix B. List of Acronyms

AFF	automated field fire
ANEV	annual net equivalent value
AR	Army Regulation
ARF	automated record fire
ASTM	American Society for Testing Materials
ATC	U.S. Army Aberdeen Test Center
ATSC	U.S. Army Training Support Center
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COTS	commercial off-the-shelf
CPQC	Combat Pistol Qualification Course
CWA	Clean Water Act
DESA	Defense Evaluation Support Activity
DoD	Department of Defense
ECAM	Environmental Cost Analysis Methodology
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
ft^3/yd^3	cubic feet per cubic yard
kg/m^3	kilograms per cubic meter
L/m^3	Liters per cubic meter
lb/ft^3	pounds per cubic feet
lb/yd^3	pounds per cubic yard
mg/kg	milligram per kilogram
mg/L	milligram per liter
mm	millimeter
MOUT	Military Operations in Urban Terrain
NEPA	National Environmental Policy Act
OSHA	Occupational Safety and Health Administration
ppm	parts per million
ppb	parts per billion
RCRA	Resource Conservation and Recovery Act
REC	Record of Environmental Consideration
REST	Range Evaluation Software Tool
SACON	shock-absorbing concrete
SDZ	safety danger zone
TCLP	Toxic Characteristic Leaching Procedure
USAEC	U.S. Army Environmental Center
USEPA	U.S. Environmental Protection Agency
USMA	U.S. Military Academy